SUPPORT FOR RAPID ENVIRONMENTAL ASSESSMENT USING AIRBORNE LIDAR TECHNOLOGY

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ABSTRACT

In April 2000, the US Army/Navy JALBTCX participated in the NATO-led Peace Support Operation exercise LINKED SEAS 2000 (LS00) in Portugal. A main focus for the LS00 exercise was to evaluate a variety of sensors and tools for rapid environmental assessment. This concept is founded on the use of existing technologies from a variety of platforms including ships, aircrafts, and satellites to fully and rapidly quantify the environment in areas of rising military tension. These data would serve to initialize models for environmental forecasting if hostile conflict arises.

During this exercise, the JALBTCX's SHOALS lidar system demonstrated its capabilities for rapidly and accurately collecting nearshore bathymetry and adjacent topography for use in planning amphibious landings. Using state-of-the-art lidar technology from a Twin Otter aircraft, SHOALS collects 400 soundings and elevations per second with an accuracy of 15 cm in the vertical and 3 m in the horizontal.

At the LS00 mission, SHOALS proved its capabilities for remote-area measurement. During a 2-day deployment, SHOALS traveled 1000 km from the air base to Porto Santo located in the difficult-to-access Madeira Islands. During the survey mission, data were collected from the shoreline to depths of approximately 40m at three different sites. A total of 2 million soundings and elevations were collected over areas totaling 20 km^2.

This paper will introduce the role of airborne lidar mapping and charting for rapid environmental assessment of sensitive areas by presenting the SHOALS results from the LS00 exercise.

1. INTRODUCTION

Most military deployments of today are initiated at short notice and involve maneuvering of maritime forces in highly variable littoral waters that are not well known and where opponents pose a significant threat (NATO, 2000). Such sensitive areas include Iraq, Bosnia, and Timor. In addition, force projection has changed drastically over the past decade (and continues to evolve) requiring faster, more flexible capabilities in order to effectively, and with minimal risk, deploy rapidly worldwide. Further challenges are created by the requirements to perform missions spanning the continuum of military operations and now including crisis response, peace support and humanitarian operations. Our military must continually train and bring new techniques and technologies into operation to be ready to respond to the most challenging problems.

In April 2000, the North Atlantic Treaty Organization (NATO) conducted the LINKED SEAS 2000 (LS00) peace support training exercise (NATO, 2000). The LS00 objective was to resolve a border conflict between two fictional non-NATO countries. The theater of operation covered the eastern Atlantic Ocean including the Bay of Biscay, northwestern Spain, and the mainland and Madeira Archipelago of Portugal. The LS00 focused on NATO's evolving military vision for crisis response, peace support and humanitarian operations, possibly conducted beyond its normal area of responsibility.

NATO's focus on crisis response operations has fundamentally changed the nature of ocean and coastal support requirements. To ensure the safe and effective deployment of maritime forces, commanders now require a capability to rapidly characterize regions of interest. A primary goal of LS00 was to include a Rapid Environmental Assessment (REA) operation to support

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80 Warships, 2 Marine Battalions, 11 Special Forces Teams, and 125 aircraft (Fig. 1.1). REA objectives included characterization of physical, meteorological and hydrodynamic properties of a proposed amphibious landing site. An important component for REA is accurate and detailed terrain mapping.

Fig. 1.1: LS00 amphibious landing exercises.

A primary objective of the LS00 REA Team was to test operational assets for rapidly carrying out a coordinated environmental reconnaissance operation employing air, sea, and space sensors combined with archived data searches and computer modeling. The purpose was to fuse data and information in order to characterize unfamiliar littoral operating areas. One such system used by the LS00 REA Team was the SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system for mapping and charting. SHOALS is operated through the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), a partnership between the US Army Corps of Engineers (USACE) and the US Naval Meteorology and Oceanography Command Naval Oceanographic Office (NAVOCEANO). The JALBTCX's main goal for participating in the REA and LS00 was to demonstrate, using a state-of-the-art system, the potential value of airborne lidar mapping and charting to support the warfighter.

This paper covers airborne lidar hydrography (ALH) and SHOALS technology and highlights the LS00 mission. Results from this operation clearly demonstrated that airborne lidar could significantly contribute to rapid characterization of unfamiliar littoral operating areas.

2. AIRBORNE LIDAR HYDROGRAPHY

An airborne lidar hydrography system uses lidar technology to directly measure water depths. A laser transmitter/receiver (transceiver) mounted on an aircraft transmits a laser pulse that travels to the air-water interface where a portion of this energy reflects back to the transceiver (Guenther *et al.*, 1996). The remaining energy propagates through the water column and reflects off the sea bottom. The water depth comes directly from the time lapse between the surface return and the bottom return, and each sounding is appropriately corrected for surface waves and water level fluctuations (Fig. 2.1).

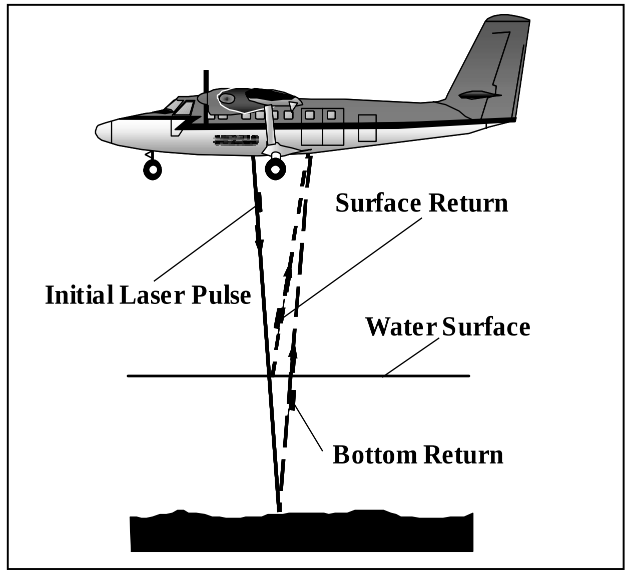

Fig. 2.1: ALH operating principle.

In practical application of this technology, laser energy is lost due to refraction, scattering, and absorption at the water surface, sea bottom, and as the pulse travels through the water column (Fig. 2.2). The combination of these effects limits the strength of the bottom return and therefore limits the maximum detectable depth. Optical water clarity is the most limiting factor for ALH depth detection. Typically, an ALH collects through depths equal to three times the Secchi (visible) depth.

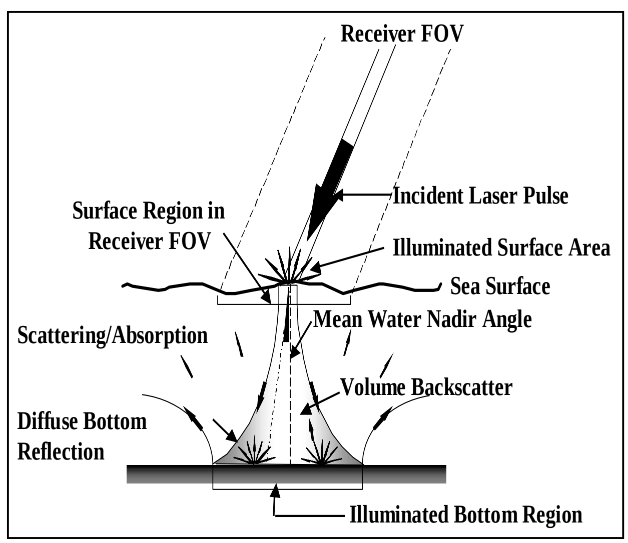

Fig. 2.2: Water column and interface effects on system performance.

2.1 The SHOALS System

In 1994, the USACE completed development of the SHOALS system, and it became the first fully operational ALH system available for use by the Department of Defense (Lillycrop *et al*., 1996 and Irish, *et al*., 2000). The SHOALS system uses a scanning, pulsed, infrared (1064 nm) and blue-green (532 nm) laser transmitter with four receiver channels mounted on either a fixed-wing Twin Otter, a Bell 212 helicopter, or other aircraft-of-opportunity (Fig. 2.3). Infrared and blue-green frequencies were selected to optimize air-water interface detection and water penetration, respectively. Typically, SHOALS operates at an altitude of 300 m and a speed of 50 m/s giving a survey swath width of 110 m and a horizontal spot density of 4 m. SHOALS survey rate is nominally 16 km^2 per hour.

Fig. 2.3: SHOALS system mounted on a Twin Otter.

Two receiver channels record energy versus time (waveforms) for each reflected blue-green pulse and one records waveforms for the reflected infrared pulse. The fourth channel records a red Raman (645 nm) energy that results from excitation of the surface water molecules by the blue-green energy. SHOALS uses the two blue-green waveforms to determine the bottom interface where one is for shallower depths and the other for deeper depths to 60 m. To avoid problems associated with air-water interface detection, SHOALS uses any of two waveforms to determine this interface accurately. Prioritized by order of use, these are the Raman then infrared channels. The infrared channel is also used to discriminate between land and water returns.

In response to the USACE's need to map the upland beach, dunes, and above-water portion of coastal structures, SHOALS was modified in 1996 to include topographic capabilities. Unlike most topographic lidar systems, which use an infrared frequency, SHOALS uses its blue-green frequency to measure topographic elevations.

SHOALS positioning comes either from differential global positioning system (DGPS) provided by US Coast Guard beacons and OMNISTAR (owned and operated by Fugro NV) satellite system or from kinematic GPS (KGPS) provided by local stations. When SHOALS operates with DGPS, vertical referencing is provided via standard water-level measurement and/or modeling. With DGPS, which provides horizontal aircraft position, horizontal and vertical accuracy are ±3 m and ±15 cm, respectively. When SHOALS operates with KGPS, which additionally provides vertical aircraft position, horizontal accuracy improves to ±1 m. An inertial reference system mounted with the laser optics accounts for aircraft motion effects.

Data collected with SHOALS meets USACE Class 1 and International Hydrographic Organization (IHO) Order 1 standards. Through independent testing, both the US National Ocean Service (NOS) and NAVOCEANO verified that SHOALS met IHO charting standards (Riley, 1995 and Pope *et al*., 1997). Additionally, the USACE conducted extensive field tests to ensure that SHOALS met their Class 1 survey standards, which are more restrictive than the IHO standards. Table 1 summarizes SHOALS current performance characteristics.

Table 1: SHOALS performance specifications.

Maximum Depth	to 60 m
Vertical accuracy	±15 cm
Horizontal accuracy	
DGPS	±3 m
KGPS	±1 m
Sounding density	4-m grid (variable)
Operating altitude	300 m (variable)
Scan swath width	110 m (variable)
Operating speed	50 to 70 m/s

In addition to the lidar depth and elevation measurements, a geo-referenced down-look video camera provides a visual record of the survey area. These video recordings are frequently used to assist with positioning coastal structures, navigation aids, piers, and other objects of interest. Additionally, the video serves as an auxiliary check for anomalous data.

2.2 Advantages of ALH for REA

As it exists today, ALH (specifically the SHOALS system) has three obvious advantages over conventional

swath-fathometer surveys for REA (Figure 2.4). Firstly, operation from an airborne platform allows data collection over large areas at rates that are several orders of magnitude faster than those of ship-based swath-fathometer surveys. This results in a significant decrease in mission deployment duration.

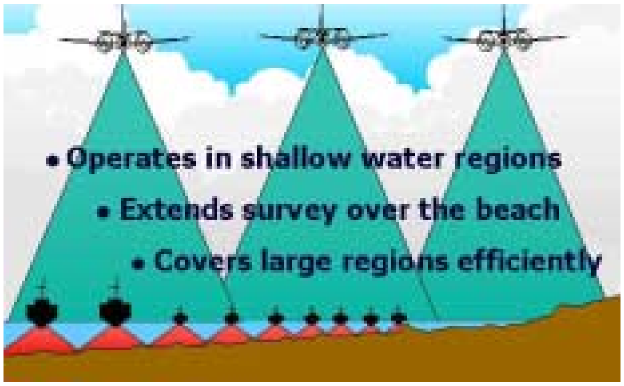

Fig. 2.4: Operating principle of ALH versus swath fathometer.

The second major advantage of ALH over conventional depth-measurement methods is its ability to measure depth in very shallow areas. Because ship-based sensors cannot safely navigate in depths shallower than 2 meters, swath-fathometer technology cannot be used to measure these shallow depths. Detection and mapping of underwater pinnacles, shoal features, and other objects with shallow depths are necessary for tactical planning.

Finally, SHOALS ability to simultaneously collect water depths and topographic elevations results in complete mapping of the beach and nearshore. Continuous data collection through the land/water interface allows for accurate shoreline positioning. Seamless terrain models from the nearshore through the adjacent upland area are beneficial to LOTS (Logistics Over The Shore) and other tactical operations.

3.0 SHOALS LS00 MISSION

3.1 Data Collection

On 11 April, five SHOALS program personnel mobilized to Portugal (Fig. 3.1). The first task was to establish a data processing office in a local hotel near NATO's South Atlantic Headquarters (SOUTHLANT). On 12 April, the aircraft, with two pilots and one flight engineer, arrived at a Portuguese Air Force base located in Sintra. The SHOALS REA mission required bathymetric surveys of Pinheiro da Cruz and Porto

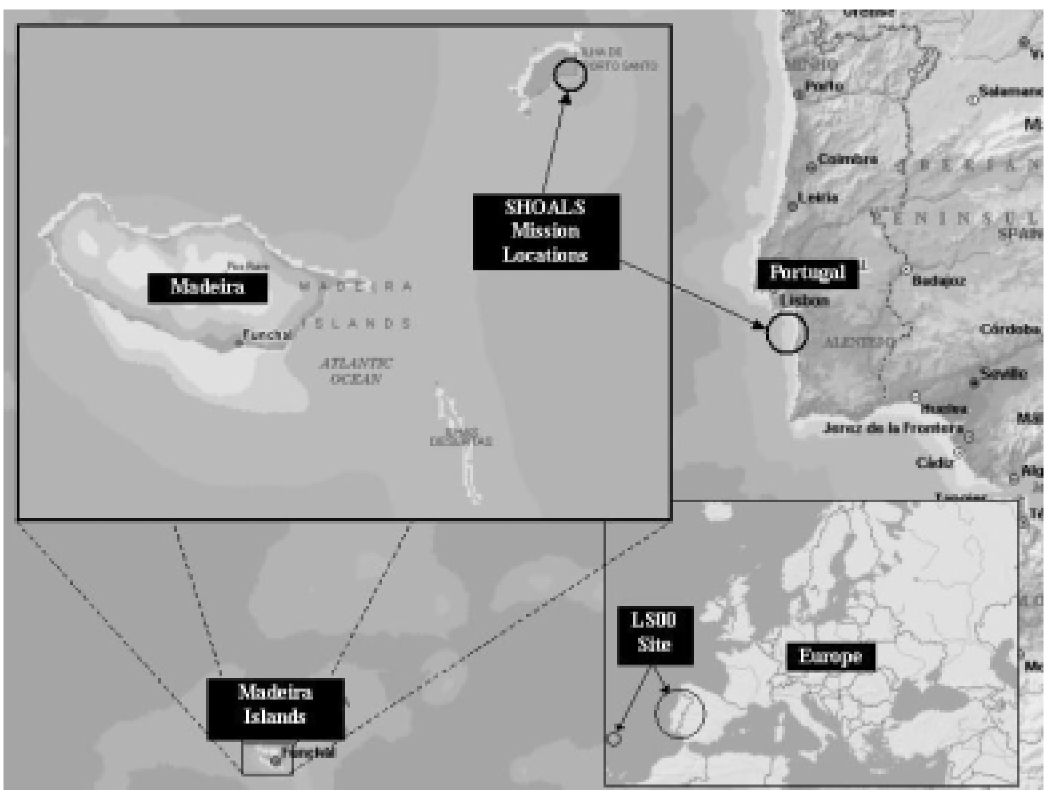

Fig. 3.1: Project location map (maps from Microsoft Encarta 99).

Santo, Madeira. Pinheiro da Cruz is located about 30 km south of Lisbon, and is an unpopulated stretch of coast consisting of high sand dunes and wide beaches (Fig. 3.2). Porto Santo, Madeira is located 1,000 km offshore of Portugal and included three small survey sites. Two of these sites are perched between rock headlands and the third is located along the open coast next to the main harbor (Fig. 3.3).

Fig. 3.2: Pinheiro da Cruz, Portugal (April 2000).

Fig. 3.3: Porto Santo, Madeira, Portugal (April 2000).

On 12 April, flight planning for the first scheduled SHOALS flight began. Meteorology and oceanography forecasts were produced and provided by the LS00 REA Team and survey flight-line planning utilized navigation charts provided by NAVOCEANO. For each planned survey flight, land elevations, water depths, video imagery, and digital pictures of the area were to be collected. The first flight was scheduled for 13 April; however, a conflicting and unrelated military live-fire training exercise in the Pinheiro da Cruz operational area prevented SHOALS from receiving area clearance until 16 April.

On 16 April, weather conditions were very poor with steady onshore winds around 25 to 30 knots and sea/swell with wave heights between 3 and 5 m. Regardless, the SHOALS flight was performed and lasted approximately 4 hours, covering the required 16-km section of coastline, centered at Pinheiro da Cruz.

Despite the adverse and challenging conditions, the flight was very successful. Beach elevations up to 14 m (above mean lower low water (MLLW)) and water depths to 22 m (MLLW) were collected throughout the area. However high surf prevented SHOALS from fully measuring across the surf zone. Early on the morning of 17 April, SHOALS was again given area clearance and completed the survey by taking advantage of slightly calmer morning weather conditions. Overnight the surf had subsided so it was possible to collect data in most of the very shallow portion of the area (depths between 0 and 2 m). Figure 3.4 shows a subset of the Pinheiro da Cruz SHOALS dataset.

On 18 April, SHOALS flew to Porto Santo, in the Madeira Islands, to survey three beaches that were being used for LS00 amphibious operations. On 19 April, SHOALS surveyed the three sites and returned to Sintra, Portugal. This concluded SHOALS aircraft operations for LS00 and on 21 April, the SHOALS system departed Portugal to return to the US.

3.2 Data Processing and REA Product Generation

Following each survey flight, data were processed at the hotel to produce elevations and positions: approximately 100,000 measurements per km^2. Depths and land elevations were adjusted to MLLW using numerically predicted tide levels provided by the LS00 REA Team. Once the depths and elevations were processed and checked using SHOALS' standard processing tools and approaches, maps and charts were created for the LS00 REA and amphibious teams. For both the Pinheiro da Cruz and the Porto Santo surveys, 24 to 36 hours were typically required to complete this process with two people processing data and one person generating the maps and charts. Hard-copy maps and charts were produced on-site using a large format HP750c plotter. In addition to the terrain data, SHOALS' digital pictures of the area were incorporated into the final plots, and a digital version of the down-look video was provided on CDROM for use by the amphibious landing planners.

The final product for the Pinheiro da Cruz site was an unclassified NAVOCEANO Special Tactical Oceanographic Information Chart (STOIC) consisting of color contoured elevations and a variety of ancillary information, including the SHOALS survey, landing site pictures, beach survey and cross sections, and sea bottom type. The STOIC was produced at NAVOCEANO and digitally transmitted to the theater where it was plotted

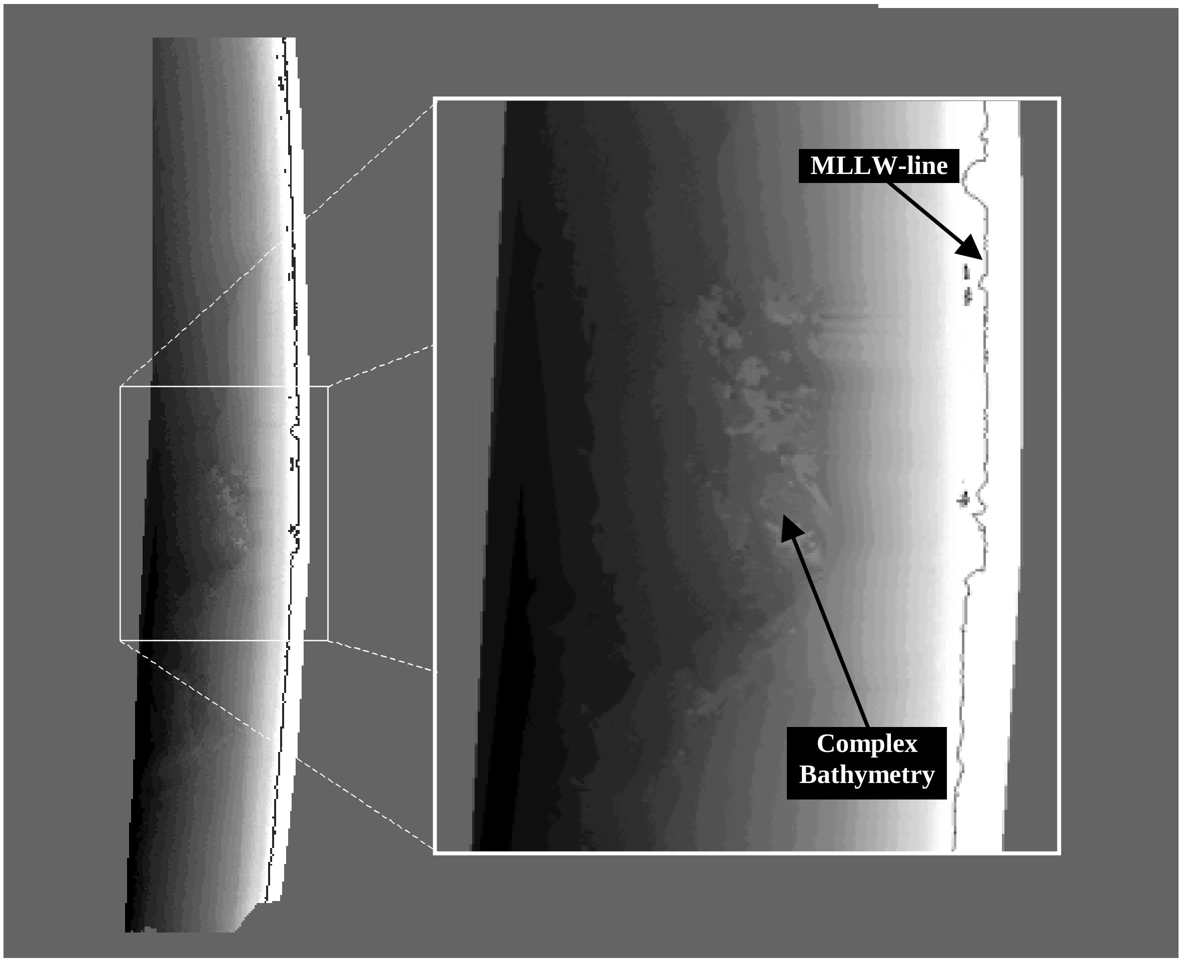

Fig. 3.4: SHOALS bathymetry and topography at Pinheiro da Cruz, Portugal (April 2000). Deeper depths are darker. North is to top.

and disseminated to those planning the landing operations.

The final products for the three Porto Santo sites were similar to the NAVOCEANO STOIC, but were produced on-site by the SHOALS team. These products were generated in the field specifically to test the ability to create and disseminate final products in-theater. In addition to these final products, a preliminary version of the Pinheiro da Cruz product, produced by the SHOALS team, was given to SOUTHLANT on 22 April, just prior to the remaining SHOALS personnel return to the US.

4.0 DISCUSSION

The objective of the LS00 REA was to use operational assets for rapidly carrying out a coordinated environmental reconnaissance operation employing air, sea, and space sensors combined with archived data searches and computer modeling. The purpose was to fuse data and information in order to accurately characterize unfamiliar littoral operating areas. The SHOALS schedule and products for the LS00 REA were designed with this thrust in mind and to develop and convey detailed information about each site.

The JALBTCX's objective in participating was to introduce airborne lidar technology and capability to the military in an operational venue. Through 6 years of operating SHOALS around the world, it has become clear that the technology can provide a unique capability to the warfighter by providing rapid coverage of the coastal zone, including both hydrographic and topographic data.

SHOALS' final products for the REA included color contoured depths, beach elevations, and beach survey cross-sections plotted along several transects through the amphibious landing zone. This presentation of the data provided the warfighter with instant knowledge of depths, obstacles, and hazards so that a safe approach could be made. The beach surveys accurately measured the beach slope and width so that decisions on

appropriate vehicles could be made a priori to the landing. To augment the survey information, digital pictures collected during each flight were included on the final plots, thus giving the warfighter and planner visual detail of vegetation and other potential hazards.

Conventional methods for collecting the nearshore and beach survey data in a denied area involve covert operations with SEAL units. Generally, scuba divers collect terrain data along widely spaced profiles (Fig. 4.0). This type of operation is not only time-consuming, but it also exposes the divers to hostile conditions.

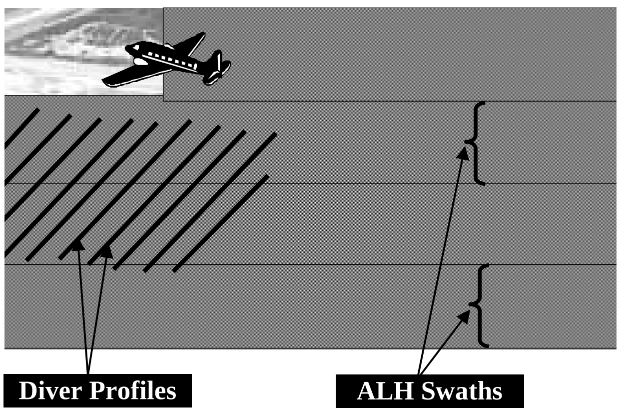

Fig. 4.1: ALH operating principle versus conventional diver surveys.

With an ALH system like SHOALS, more detailed and accurate terrain data can be collected much faster. For example, a 1-km^2 area surveyed with SHOALS comprises 100,000 depth and elevation measurements and is completed in a few minutes. Whereas, a diving operation would require several hours and produce a much coarser, and therefore less detailed, terrain model.

Another advantage of SHOALS and ALH was experienced during LS00: the SHOALS system's ability to successfully survey in rough weather conditions was proven. Since this was a training exercise, conventional assets were planned to survey the landing area as well. However, on the planned survey day, as well as many days on either side, severe weather conditions prevented both SEAL teams and hydrographic survey vessels from operating. Since SHOALS was airborne, the 3 m to 5 m sea and swell did not impede operations. As a result, SHOALS was the only asset able to complete the survey of the landing site before the planned operation.

In addition to paper products, all data collected by SHOALS were provided to the LS00 REA Team for other uses. Digital elevations and depths were used to create grids for numerical forecast models and the video was useful in gaining a qualitative understanding and knowledge of the area.

5.0 CONCLUSIONS

SHOALS' participation in NATO's LS00 REA in Portugal, demonstrated its capability for rapidly and accurately collecting hydrographic and topographic data for use in planning amphibious landings. In addition, SHOALS was the only system (of those participating in LS00) capable of collecting data during moderate wind and rough surf conditions. SHOALS' ability to collect bathymetry, topography, and supporting ancillary data, at aircraft speeds, led one LS00 participant to comment "SHOALS put the Rapid in REA."

SHOALS clearly demonstrated its abilities and the potential for airborne lidar technology to support the warfighter. However, as SHOALS exists now, it is a defenseless system, and it could not participate in an REA mission in an actual denied area. The LS00 REA training exercise did provide the JALBTCX with the opportunity to gain valuable experience and knowledge of the warfighter's requirements. This is now being used to initiate a development program to miniaturize SHOALS' capabilities into a package that will operate on an unmanned aerial vehicle (UAV). The sensor is intended to provide the same capabilities currently operational on SHOALS, but in a package capable of fitting into several UAV or pods. In addition to miniaturization, the sensor will be much more automated to minimize field crew size and final product turnaround time. With this new capability, the warfighter of the future will have rapid and safe access to accurate terrain detail and a visual assessment of unknown littoral waters and adjacent landmasses for better planning and execution of maritime activities.

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